## Chemical Reactions

## and Energy Calculations

## Learning Outcomes

1. Calculate formal weights and molecular weights.
2. Identify balanced chemical equations.
3. Write balanced chemical equations

Calculating Formula Mass:

## Mass of a Molecule or Formula Unit



What is the mass (in amu) of one molecule of $\mathrm{BF}_{3}$ ?

$$
\begin{gathered}
m_{\mathrm{BF}_{3}}=a \cdot m_{\mathrm{B}}+b \cdot m_{\mathrm{F}} \\
m_{\mathrm{BF}_{3}}=1 \cdot m_{\mathrm{B}}+3 \cdot m_{\mathrm{F}} \\
m_{\mathrm{BF}_{3}}=(1)(10.81 \mathrm{amu})+(3)(19.00 \mathrm{amu}) \\
m_{\mathrm{BF}_{3}}=67.81 \mathrm{amu}
\end{gathered}
$$

## Problem 1

What is the mass (in amu) for one water molecule?

## Problem 2

What is the mass (in amu) for one molecule of carbon dioxide?

## Problem 3

What is the formal weight (in amu ) for NaCl ?

## Molecular and Empirical Formulas

Molecular Formula: Gives the exact number of atoms that make up a molecule.

Empirical Formula: Gives the ratio of atoms to one another in a molecule.

## Problem 4

The molecular formula for hydrogen peroxide is $\mathrm{H}_{2} \mathrm{O}_{2}$. What is the empirical formula?

## Browning of Food

## Créme Brûlée



## Browning of Food

## Onions



## Browning of Food

## Sugar



## Caramelization



## Caramelization



## Maillard Reaction

## A GUIDE TO THE MAILLARD REACTION

The Maillard reaction occurs during cooking, and it is responsible for the non-enzymatic browning of foods when cooked. It actually consists of a number of reactions, and can occur at room temperature, but is optimal between $140-165^{\circ} \mathrm{C}$. The Maillard reaction occurs in three stages, detailed here.

1
The carbonyl group on a sugar reacts with a protein or a mino acid's amino group, producing an N -substituted glycosylamine.



SUGAR (GLUCOSE)
AMINO GROUP $\longrightarrow$
GLYCOSYLAMINE (+ WATER)

2
The glycosylamine compound generated in the first step isomerises, by undergoing Amadori rearrangement, to give a ketosamine.


3
The ketosamine can react in a number of ways to produce a range of
different products, which different products, which themselves can react further.


FISSION PRODUCTS


REDUCTONES
$\square$


HYDROXYMETHYLFURFURAL

## Classes of Maillard Reaction Products



## 8

$\square$


The Maillard reaction produces hundreds of products; a small subset of these contribute to flavour and aroma, some groups of which are described below. Melanoidins are also formed, brown, polymeric substances which contribute to the colouration of many cooked foods.


FURANONES
sweet
caramel
burnt


PYRROLES
cereal-like
nutty


FURANS meaty burnt caramel-like


ALKYLPYRIDINES
bitter burnt
astringent


OXAZOLES green nutty sweet


ACYLPYRIDINES cracker-like cereal


THIOPHENES meaty
roasted roasted

## Physical and Chemical Changes

A physical change is a change that alters only the state or appearance of matter, but not its composition. A chemical change is a change that alters the composition of matter.

Quartz!!


Physical Change


Silver (Ag)
Silver(II) Oxide $\left(\mathrm{Ag}_{2} \mathrm{O}\right)$


Chemical Change


# Physical and Chemical Changes 

Physical Change
Chemical Reaction


## Chemical Equations: Banana Split!

Reactants $\longrightarrow$ Products

## Chemical Equations Indicate the State of Matter

| State | Symbol |
| :---: | :---: |
| $s$ | Solid |
| $l$ | Liquid |
| $g$ | Gas |
| $a q$ | Aqueous (Ions Dissolved In Water) |

## Balancing Chemical Equations: Banana Split!

## Reactants $\longrightarrow$ Products



Banana (s) + Ice Cream Scoop (s) $\longrightarrow$ Banana Split (s)
1 Banana $(\mathrm{s})+3$ Ice Cream Scoops $(\mathrm{s}) \longrightarrow 1$ Banana Split $(\mathrm{s})$

## Balancing Chemical Equations


$\mathrm{CH}_{4}(\mathrm{~g})+\mathrm{O}_{2}(\mathrm{~g}) \longrightarrow \mathrm{CO}_{2}(\mathrm{~g})+\mathrm{H}_{2} \mathrm{O}(\mathrm{g})$

## Balancing Chemical Equations



## Balancing Chemical Equations


$\mathrm{CH}_{4}(g)+2 \mathrm{O}_{2}(g) \longrightarrow \mathrm{CO}_{2}(g)+2 \mathrm{H}_{2} \mathrm{O}(g)$

## What Does it Mean to Balance?




## Balancing Chemical Equations Time!

## Balancing chemical equations time!



## Problem 5

## Balance the following chemical equation for the oxidation of ethanol:

$\mathrm{CH}_{3} \mathrm{CH}_{2} \mathrm{OH}(\mathrm{I})+\mathrm{O}_{2}(\mathrm{~g}) \rightarrow \mathrm{CH}_{3} \mathrm{COOH}(\mathrm{aq})+\mathrm{H}_{2} \mathrm{O}(\mathrm{I})$


## Problem 6

Balance the following chemical equation for photosynthesis:
$\mathrm{CO}_{2}(\mathrm{~g})+\mathrm{H}_{2} \mathrm{O}(\mathrm{I}) \rightarrow \mathrm{O}_{2}(\mathrm{~g})+\mathrm{C}_{6} \mathrm{H}_{12} \mathrm{O}(\mathrm{aq})$

## Problem 7

## Balance the following chemical equation for the combustion of methane:

$$
\mathrm{CH}_{4}(\mathrm{~g})+\mathrm{O}_{2}(\mathrm{~g}) \rightarrow \mathrm{CO}_{2}(\mathrm{~g})+\mathrm{H}_{2} \mathrm{O}(\mathrm{~g})
$$

## Problem 8

## Balance the following chemical equation for the rusting of iron:

$$
\mathrm{Fe}(\mathrm{~s})+\mathrm{O}_{2}(\mathrm{~g}) \rightarrow \mathrm{Fe}_{2} \mathrm{O}_{3}(\mathrm{~g})
$$



## Learning Outcomes

1. Explain what a mole is and why it is used.
2. Recognize the numerical relationship between chemical quantities in a balanced chemical equation.
3. Use the molar mass to convert between mass and mole.
4. Use Avogadro's number to convert between amount and mole.
5. Convert between grams of a compound and grams of another compound.

## Problem 9

What unit of measured is used to purchase the following:
(a) Gasoline
(b) Meat
(c) Gold

Define how many dozen of the following objects you have. Use dimensional analysis and show all units.
(a) 12 eggs
(b) 24 paper sheets
(c) 18 cupcakes

## Problem 11

## Ran the following in order of increasing number:

5 dozen quarters, 12 dozen cattle, 3.5 dozen movies

## Problem 12

Select the dozen that weighs more:
(a)

Eggs or Cats

(b)

## Sand Grains or Tennis Balls

## Problem 13

Select the grouping that has more particles.
(a)

A gallon of marbles or a gallon of sand
(b)

25 mL of water or 25 mL of corn kernels

## Problem 14

1 L of water contains $3.34 \times 10^{25}$ molecules.
Do you think a dozen is a good way to group the number of water molecules? Explain.

## What is a Mole?



## Mole Definition

A mole is a "chemist's" dozen!

Just as 1 dozen = 12 of anything,
1 mole $=6.023 \times 10^{23}$ of anything

## Avogadro's Number

$$
N_{\mathrm{A}}=\frac{6.023 \times 10^{23} \mathrm{units}}{1 \text { mole units }}
$$

## A Mole Can Be Anything!!

1 dozen cats = 12 cats,
1 mole cats $=6.023 \times 10^{23}$ cats

## Chemical Equations Revisited

How many iron atoms are needed to prepare two formula units of iron oxide?

$$
4 \mathrm{Fe}(\mathrm{~s})+3 \mathrm{O}_{2}(\mathrm{~g}) \rightarrow 2 \mathrm{Fe}_{2} \mathrm{O}_{3}(\mathrm{~g})
$$



## Problem 15

What is the mass of 4 iron atoms. Note, $\mathrm{m}_{\mathrm{Fe}}=55.85 \mathrm{amu}$ and $1 \mathrm{amu}=1.66 \times 10^{-24} \mathrm{~g}$.

## Chemical Equations Revisited

How many dozens of iron atoms are needed to prepare two dozen formula units of iron oxide?

$$
4 \mathrm{Fe}(\mathrm{~s})+3 \mathrm{O}_{2}(\mathrm{~g}) \rightarrow 2 \mathrm{Fe}_{2} \mathrm{O}_{3}(\mathrm{~g})
$$



## Chemical Equations Revisited

How many moles of iron atoms are needed to prepare two moles of iron oxide?

$$
4 \mathrm{Fe}(\mathrm{~s})+3 \mathrm{O}_{2}(\mathrm{~g}) \rightarrow 2 \mathrm{Fe}_{2} \mathrm{O}_{3}(\mathrm{~g})
$$



Why Do the Elements Not

## Have Units for the Mass on the Periodic Table?



## Problem 16

What is the mass of 4 moles of iron. Note, $\mathrm{m}_{\mathrm{Fe}}=55.85 \mathrm{~g} / \mathrm{mol}$.

## A Recipe is a Source of Ratios

1 Pizza Dough Round +31 Pepperoni Slices +2 Olive Slices +250 Cheese Shreds $\longrightarrow$ Pizza


## A Recipe is a Source of Ratios

1 Pizza Dough Round +31 Pepperoni Slices +2 Olive Slices +250 Cheese Shreds $\longrightarrow$ Pizza

## 1 Pizza Dough Round : 31 Pepperoni Slices

2 Olive Slices : 250 Cheese Shreds
1 Pizza Dough Round : 1 Pizza
2 Olive Slices : 1 Pizza


## Problem 17

What ratios can be gathered from the following chemical equation?

$$
3 \mathrm{H}_{2}(\mathrm{~g})+\mathrm{N}_{2}(\mathrm{~g}) \longrightarrow 2 \mathrm{NH}_{3}(\mathrm{~g})
$$



A chemical equation is a recipe of ratios!

## Problem 18

Methane $\left(\mathrm{CH}_{4}\right)$ undergoes combustion according to the following reaction:

$$
\mathrm{CH}_{4}(\mathrm{~g})+2 \mathrm{O}_{2}(\mathrm{~g}) \longrightarrow \mathrm{CO}_{2}(\mathrm{~g})+2 \mathrm{H}_{2} \mathrm{O}(\mathrm{~g})
$$



If the figure above represents the amount of oxygen available to react, which of the following figures best represents the amount of $\mathrm{CH}_{4}$ required to completely react with all of the oxygen?

(a)

(b)

(c)

## Problem 19

Calculate how many moles of HCl form when 1.75 mol of $\mathrm{H}_{2}$ reacts with $\mathrm{Cl}_{2}$. You may assume that there is excess $\mathrm{Cl}_{2}$.

$$
\mathrm{H}_{2}(\mathrm{~g})+\mathrm{Cl}_{2}(\mathrm{~g}) \longrightarrow 2 \mathrm{HCl}
$$

## Problem 20

Calculate how many grams of MgO form when 2.4 g of Mg reacts with $\mathrm{O}_{2}$. You may assume that there is excess $\mathrm{O}_{2}$.

$$
2 \mathrm{Mg}(\mathrm{~s})+\mathrm{O}_{2}(\mathrm{~g}) \longrightarrow 2 \mathrm{MgO}(\mathrm{~s})
$$

Calculate how many grams of NaOH form when 2.4 g of $\mathrm{Na}_{2} \mathrm{O}$ reacts with $\mathrm{H}_{2} \mathrm{O}$. You may assume that there is excess $\mathrm{H}_{2} \mathrm{O}$.

$$
\mathrm{Na}_{2} \mathrm{O}(\mathrm{~s})+\mathrm{H}_{2} \mathrm{O}(\mathrm{l}) \longrightarrow 2 \mathrm{NaOH}(\mathrm{aq})
$$

